AFRL-VA-WP-TP-2002-306

CONTROL SCIENCE CENTER OF EXCELLENCE (CoE)

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APRIL 2002

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AIR VEHICLES DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 2002	Preprint, 01/01/1998 – 03/01/2002

4. TITLE AND SUBTITLE
Control Science Center of Excellence (CoE)

5. FUNDING NUMBERS
C: In-House
PE: 61102F
PR: 2304
TA: F2
WU: 01

6. AUTHOR(S)
David Leggett

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Control Theory Optimization Branch (AFRL/VACA)
Control Sciences Division
Air Vehicles Directorate
Air Force Research Laboratory
Wright-Patterson Air Force Base, OH 45433-7542

8. PERFORMING ORGANIZATION REPORT NUMBER

AFRL-VA-WP-TP-2002-306

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AIR VEHICLES DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542
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10. SPONSORING / MONITORING AGENCY REPORT NUMBER

AFRL-VA-WP-TP-2002-306

11. SUPPLEMENTARY NOTES
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Article submitted for publication to *Technology Horizons* in its September 2002 issue.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 Words)***

14. SUBJECT TERMS

15. NUMBER OF PAGES
8

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

CONTROL SCIENCE CENTER OF EXCELLENCE

Advancing control science for air and space forces of the 21st Century.

AFRL's Air Vehicles Directorate, Control Sciences Division, Control Theory Optimization Branch, Wright-Patterson AFB, OH.

The Air Vehicles Directorate formed the Control Science Center of Excellence (CoE) in 1998. The mission of the Control Science CoE is to plan and conduct basic research and exploratory development in advanced control technology to support the Air Force in the 21st century. The CoE develops and transitions air and space vehicle control technology in the areas of flight dynamics, multivariable control theory, adaptive control theory, robust control, control optimization, system identification, and flight and space vehicle simulation and assessment.

The Control Theory Optimization Branch was established as a Center of Excellence in recognition of its consistent productivity over the last twenty years and its many fundamental technical contributions to control theory. The CoE has successfully transitioned technology to several operational systems and the scientists and engineers of the CoE have earned recognition from professional associations, universities, and other government and DoD organizations.

Adaptive Reconfigurable Control

One of the CoE's most important contributions has been the development of adaptive reconfigurable control algorithms. These algorithms provide a control system with the ability to compensate for battle damage or system failures in flight; maintaining mission capability in the case of minor damage or failures, or allowing the aircraft to get home safely in more severe cases.

The capabilities of adaptive reconfigurable control technology were demonstrated in the RESTORE program, documented in the inaugural issue of *Horizons* magazine. During the RESTORE program, the adaptive reconfigurable control algorithms were demonstrated in piloted simulations of a tailless fighter aircraft, in hardware-in-the-loop simulations of the Boeing X-36 tailless fighter demonstrator, and ultimately with a limited flight test of the X-36 with RESTORE algorithms at Edwards AFB. These demonstrations consistently proved the ability of the RESTORE algorithms to compensate for control system failures, preventing departures and providing acceptable handling qualities. Boeing subsequently adopted elements of the RESTORE control system architecture for the baseline flight control system of their X-45 Unmanned Combat Air Vehicle (UCAV).

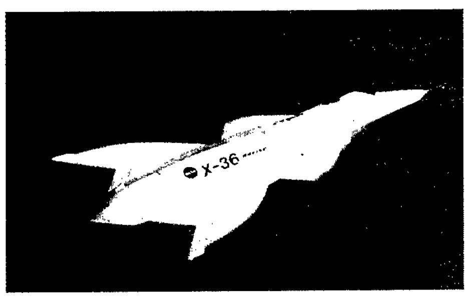

Figure 1. RESTORE technology was successfully flight tested on the Boeing X-36 tailless fighter demonstrator.

Hypersonic Guidance and Control

Successful demonstrations of adaptive reconfigurable control systems on fighter aircraft have prompted the transition of this technology to the more hostile and uncertain hypersonic flight regime. The technical challenges associated with this area include a demanding flight envelope (from launch up to Mach 25) and a military-requirement for aircraft-like operations. Unlike manually controlled aircraft, hypersonic Reusable Launch Vehicles and Future-Strike aircraft will rely on autonomous guidance systems for trajectory control. The CoE's current research focuses on the development of adaptive, fault tolerant guidance and control systems for such vehicles. These control systems are designed to compensate for failures or damage that limit the inner-loop control system's authority by modifying the trajectory commands from the guidance system on-line.

Figure 2. RESTORE technology is being incorporated in the Boeing X-45 UCAV.

The CoE was one of the teams invited to participate in NASA Marshall's Advanced Guidance and Control Project for the X-33. The purpose of this project was to develop and evaluate a number of advanced guidance and control methodologies that could replace conventional gain-scheduled, trajectory dependent control schemes that are currently used on reusable launch vehicles. The CoE team developed an adaptive/reconfigurable control system for the ascent flight phase of the X-33. The NASA Marshall evaluators praised this control law for its excellent attitude tracking ("significantly better than the baseline control system") and the reduced mission planning times associated with this approach.

Current work in this area is focused on improving the control allocation strategy to account for nonlinearities and on developing algorithms to compute the reachable area on the earth's surface following failures that restrict the vehicle's control authority. The ability to rapidly calculate this "footprint" gives the guidance system the information it needs to safely abort to an alternate landing site.

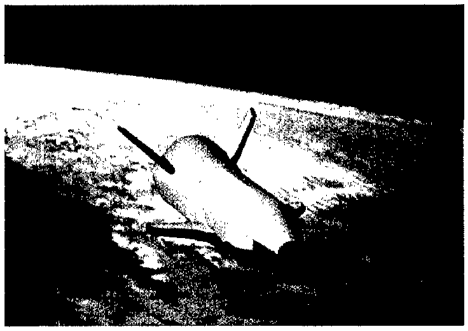

Figure 3. The Control Science CoE is developing adaptive/reconfigurable control systems for the hypersonic flight regime.

Cooperative Control of UAVs

Future UAVs will be required to operate autonomously yet cooperatively. The CoE is developing hierarchical decentralized controllers that combine guidance, real-time planning, and multi-vehicle task coordination. These controllers will enable UAVs to coordinate threat avoidance, target search, classification, attack, and battle damage assessment tasks. Also, dynamically-coupled formation controllers will allow drag-reducing flight formations and will enable in-flight refueling for UAVs. Lastly, intelligent controllers will be able to learn from experience and revise the UAV's trajectory accordingly. Key partners for much of this work are the Defense Advanced Research Projects Agency (DARPA) and the Munitions Directorate. DARPA also provides a lot of the funding for this work.

A new focus of research in this area is on the effect of information flow constraints between autonomous vehicles performing cooperative tasks. Vehicle, target, and threat information passed between vehicles is subject to delays or loss due to limited bandwidth, geographical obstructions, or electronic interference from enemy countermeasures. This could, in turn, lead to suboptimal performance or even failure to complete a cooperative task. The central question is how information flow constraints limit the performance of autonomous vehicle teams performing cooperative tasks and what can be done to optimize performance in the presence of information flow constraints.

Satellite Formation Control

A new application of feedback control for the CoE involves controlling and coordinating formations of microsatellites. The control problem is to minimize the fuel consumption necessary to maintain the formation in the presence of perturbations caused by orbital mechanics and to reconfigure the formation as missions change. In collaboration with the Space Vehicles Directorate, the CoE's satellite formation control team has developed an efficient hybrid optimization algorithm that provides formation reconfiguration with minimum use of fuel. This technology affords greater flexibility and affordability for space-based assets and is a strong candidate for incorporation in the Space Vehicles Directorate's TechSat 21 micro-satellite demonstration program.

Flow Control

Recent flow control efforts have demonstrated the ability of small-scale control devices to effect large-scale response changes through natural amplification. By coupling these advances with modern control theory, reactive flow control is within reach. The CoE's flow control effort is advancing the state of the art by integrating and applying these technologies. Potential applications include flow separation control, drag reduction, and ultimately, the ability to use these small devices in place of traditional aircraft control surfaces. A joint effort with the Air Force Academy is looking at vortex shedding off a blunt body in the Academy's water tunnel. The objective is to show that flow control can be used to suppress the vortex shedding, thus reducing drag.

People

The normal complement of the CoE consists of about a dozen civilian engineers and scientists, a couple of military engineers, and a few contractor engineers and support personnel. All of the scientists and engineers have advanced degrees; about half are Ph.D.'s. During the summer, the size of the CoE typically swells to about three dozen people with professors and graduate students from various universities working for the CoE. Many of the CoE's members have been individually recognized for technical achievements through designation as technical society Fellows, technical committee and advisory board membership, and numerous awards from the defense and aerospace community.

The bulk of the CoE's research is sponsored by the Air Force Office of Scientific Research (AFOSR). The CoE has twice been designated an AFOSR Star Team for excellence in basic research, and has received the Air Force Chief of Staff Award.

A key factor in the CoE's success is the strong partnerships it has formed with other organizations. Besides the collaborations already mentioned, the CoE is cooperating with the Navy in developing Intelligent Control algorithms for UAVs, and with several companies and universities on various aspects of cooperative control and flow control.

A new endeavor in this respect is the creation of a Collaborative Center in Control Science with Ohio State University. The Collaborative Center will augment the CoE's research by providing rapid access to a broad base of outside expertise to help accelerate research. When fully established, the Collaborative Center will give the CoE the flexibility to rapidly respond to new research directions as the needs of the Air Force change.

The Control Science CoE is dedicated to the development of advanced control technology and its rapid transition to the warfighter to improve total weapons system lethality, survivability, agility, performance and affordability. The ability to develop and apply control technologies to a wide spectrum of aerospace applications is critical to ensuring that the USAF remains the preeminent aerospace power.

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